Starch-Oil Composites Prepared by Steam Jet Cooking: Preparation, Properties, and Applications

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Development of new, nontraditional markets for cornstarch is a major research priority at the National Center for Agricultural Utilization Research. Cornstarch is inexpensive (about $0.22–$0.26/kg) and is produced in the United States in amounts that exceed current market needs. In addition to utilizing surplus starch, replacement of synthetic polymers with annually renewable, plant-derived polymers reduces our dependence on petrochemicals and also enhances polymer biodegradability. As part of our starch utilization research program, we are investigating the use of steam jet cooking as a rapid and continuous method for preparing complexes and intimate physical mixtures of starch with other monomeric and polymeric materials.

Steam jet cooking has been used commercially for decades as a rapid and continuous method for preparing starch solutions, such as in the paper industry. As shown in Fig. 20.1, cooking is carried out by pumping a starch-water slurry through a hydroheater, where it contacts a jet of high-pressure steam. Although residence time in the hydroheater is only a matter of seconds, the high cooking temperature achieved at elevated steam pressures is sufficient not only to gelatinize starch but to dissolve both the amylose and amylopectin components totally. The steam pressure in the hydroheater (and thus the temperature used for the cooking process) is varied by either opening or closing the back pressure valve. Gradual closing of this valve increases both steam pressure and cooking temperature while at the same time reducing the volume of excess steam that passes through the cooker along with the hot starch solution.

Steam jet cookers fall into two major categories (1), which have been designated as "thermal" and "excess-steam." Thermal jet cookers dissolve starch with a minimum of mechanical shear, because the steam entering the hydroheater is almost completely condensed during the cooking process, and the amount of excess steam passing through the cooker is minimal. To achieve these conditions, the steam line pressure entering the cooker and the steam pressure within the hydroheater during cooking are adjusted to about the same value. In an excess-steam jet cooker, however, the steam line pressure exceeds the cooking pressure within the hydro-
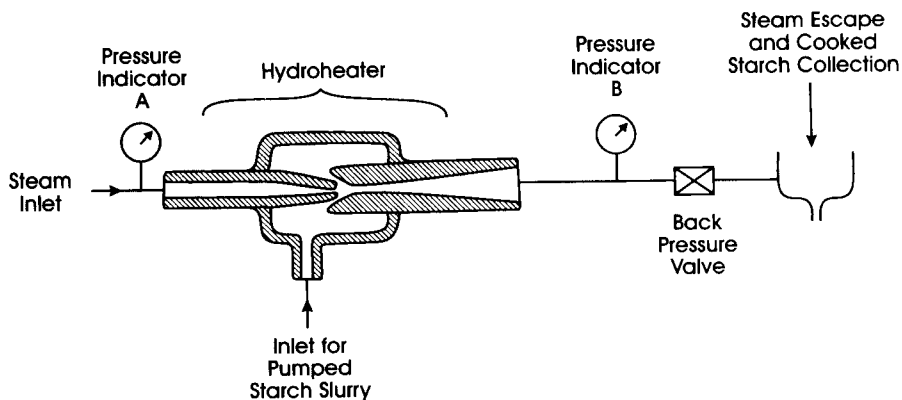

Fig. 20.1. Schematic diagram of a steam jet cooker.

heater, causing a large volume of steam to pass through the hydroheater along with cooked starch solution. This excess steam results in intense turbulence and mechanical shear during cooking and causes significant reduction in starch molecular weight. In addition to the effects caused by variations in steam pressure, the configuration within the hydroheater may also be adjusted to either minimize or maximize the intensity of mixing.

We have examined differences in shear-induced starch degradation resulting from jet cooking under thermal vs. excess steam conditions (2); results are shown in Fig. 20.2. Cooking conditions used are designated by two pressures, A/B. A is the steam line pressure entering the cooker, which was either 70 or 120 psig (0.48 or 0.83 MPa), as indicated by pressure gauge A in Fig. 20.1. B is the pressure within the hydroheater, as indicated by pressure gauge B. A designation of 70/65 would therefore be close to thermal conditions, whereas the 120/40 conditions would result in a large volume of excess steam. For waxy maize starch, normal maize starch, and waxy rice starch, the intrinsic viscosity of starch was significantly reduced when cooking was carried out under excess-steam as opposed to thermal conditions. With high-amylose starch, however, there was little difference between intrinsic viscosities obtained under the two cooking conditions, perhaps because the reduced molecular weight and hydrodynamic volume of amylose (as compared with amylopectin) make it less sensitive to mechanical shear.

Despite the widespread use of steam jet cooking by industry, the co-jet cooking of starch with other polymeric and monomeric materials had not been extensively studied prior to the research initiated at our Center. Our investigation of co-jet cooking has been quite fruitful and has shown that the high temperature and intense mixing that takes place during excess-steam jet cooking produces new starch-based materials that are not easily obtainable by other means. Initial studies were carried out with mixtures of starch and a low-molecular-weight copolymer of polyethylene and poly(acrylic acid) [EAA]. These studies showed that helical inclusion complexes are
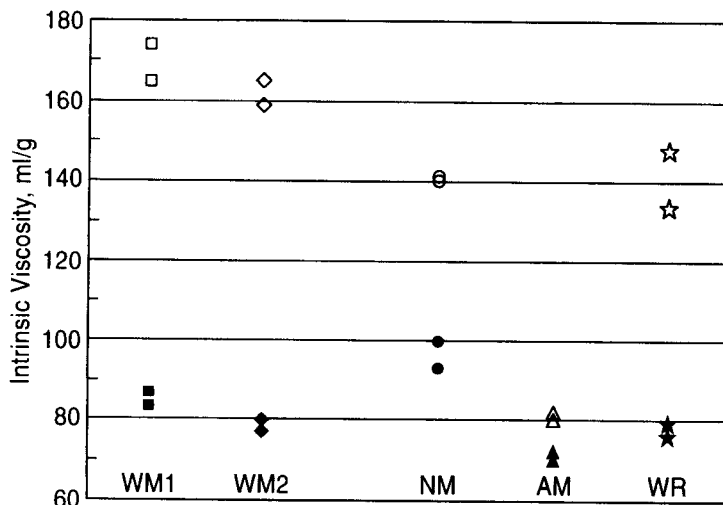
Fig. 20.2. Effect of steam pressures and starch type on the intrinsic viscosity of jet-cooked starch solutions. Open symbols: 70/65 steam. Filled symbols: 120/40 steam. WM1: waxy cornstarch, pH initially adjusted to 7.0. WM2: waxy cornstarch, no pH adjustment. NM: normal cornstarch, no pH adjustment. AM: amylomaize VII (i.e., cornstarch containing 70% amylose), no pH adjustment. WR: waxy rice starch, no pH adjustment.

produced between the two polymeric components, analogous to the well-known complexes between starch and fatty acids (3–6). Moreover, formation of these complexes provides a convenient method for altering the rheology and gelling properties of starch solutions (7–9). We have also examined the co-jet cooking of starch-hydrocolloid gum mixtures (10,11) and once again observed that co-jet cooked products had properties different from those obtained from simple mixing systems.

We next began an investigation of the co-jet cooking of aqueous starch-lipid mixtures. The objectives of this study were to determine whether new membranelike materials might be produced that would simulate those found in plants, and whether the co-jet cooking process would yield new hydrophobic starch derivatives or complexes that could function as additives or compatibilizers in starch-filled plastics. Although neither of these initial objectives was realized, the cooking process unexpectedly produced new composite materials having properties suitable for a wide range of end-use applications. These starch-lipid composites have been given the trademark Fantesk™ by the U.S. Department of Agriculture, and their preparation, properties, and commercial applications will be discussed in this chapter.

Experimental Procedures

Preparation

The following method was used to prepare a 100:20 (by weight) cornstarch–soybean oil composition and is typical of the experimental procedure used. Pure Food Powdered Cornstarch was a product of A.E. Staley Mfg. Co., Decatur, Illinois, and soybean oil was purchased locally under the trade name Wesson Vegetable Oil (Hunt Wesson Inc., Fullerton, California). Steam pressures are those read from conventional pressure gauges. A mixture of 80 g of soybean oil and 3 L of water was stirred in a Waring blender at maximum speed for about 1 min, and 400 g of cornstarch was added. The oil phase separated almost immediately when stirring was stopped. The rapidly stirred mixture was passed through a Penick & Ford laboratory model steam jet cooker operated with 70 psig (0.48 MPa) line pressure steam and a pumping rate of about 1.4 L/min. Steam pressure and temperature within the hydroheater were maintained at 40 psig (0.28 MPa) and 140°C, respectively. The hot, jet-cooked dispersion was dried on a double-drum drier (45.7 × 30.5 cm diameter), heated with 40 psig steam, and rotated at 4 rpm. The flakelike product was coarsely milled to yield a dry, flowable powder with a water content of about 5%. The starch:oil ratio and the percent starch solids in the starting mixture can both be varied within broad limits. For example, a mixture of 400 g of soybean oil and 1000 g of cornstarch in 3 L of water also yields an outwardly dry powder after jet cooking, drum drying, and milling.

Scanning Electron Microscopy (SEM)

Aqueous dispersions of Fantesk products were allowed to air-dry to continuous films. Films were then fractured, and fracture faces were extracted with ethanol and hexane to reveal domains previously occupied by oil as voids in the fracture surface. A Hitachi ISI microscope was used, and samples were sputter-coated with 60:40 gold-palladium alloy.

Light Microscopy and Transmission Electron Microscopy (TEM)

Drum-dried samples of Fantesk products were dispersed in hot water (20 g/100 mL) by stirring at high speed in a Waring blender, and dispersions were then poured into petri dishes and held overnight at 4°C. Segments were cut from the gels and sliced into 1-mm cubes. These were fixed in 2% glutaraldehyde in 0.05 M sodium phosphate buffer (pH 7.2) for 4 h at 25°C, rinsed three times in buffer only, then post-fixed in 1% osmium tetroxide in the same buffer. Samples were dehydrated in an ethanol series, embedded in LR white acrylic resin, and polymerized at 60°C. Sections for light microscopy (1 μm thick) were cut with a glass knife on a Sorvall MT-2 ultramicrotome, adhered to gelatin-coated glass slides, stained with toluidine blue, and photographed with a Zeiss bright-field oil emersion light microscope. For TEM, pale gold sections were stained with uranyl acetate and lead citrate and were then examined with a Hitachi H-500 microscope.

Analysis of Oil Droplet Size

Digital images of micrographs were captured by a monochrome video camera onto a personal computer equipped with a video capture card. Oil droplets were quantified, and their size was measured using Global Lab Image software (Data Translation, Marlboro, Massachusetts), after adjusting the images for optimum particle recognition. Analyses were based on section fields of 40,800 square microns and fracture face fields of 21,000 square microns, respectively. Values presented are the mean of 12 light micrographs or 3 SEM images per sample ± standard error.

Hexane Extraction of Fantesk Products

Drum-dried samples (1–2 g) were immersed in 100 mL of hexane for 30 min. Hexane was decanted, filtered, and evaporated to dryness, and extracted oil was determined gravimetrically. Samples were extracted three times. Over 90% of the extractable oil was removed with the first extraction, whereas the third extraction removed only negligible amounts of oil. Total oil removed in this manner is designated as *loosely bound.* Extracted samples were next dispersed in hot water, and the starch was hydrolyzed by addition of α-amylase. Hydrolyzed dispersions were transferred to separatory funnels, and liberated oil was extracted with hexane and determined gravimetrically after evaporation of hexane. Oil recovered in this manner is designated as *tightly bound.*

To determine the extractability of oil from Fantesk compositions in aqueous dispersion, samples were suspended in 80 mL of water, heated to boiling to disperse the Fantesk composite, and cooled to room temperature. Dispersions were transferred to separatory funnels and extracted with 40 mL of hexane. Each sample was extracted a total of eight times. Hexane extracts were evaporated to dryness, and extracted oil was determined gravimetrically.

Addition of Fantesk to Ground Beef

The beef used for blending with Fantesk contained 8.5% fat and was first coarsely ground. Drum-dried Fantesk products were then added at a level of 1 part per 100 parts beef, by weight. Water was then added at a level of 10 parts per 100, and the samples were passed through the grinder a second time. Patties were cooked on a preheated (170°C) griddle until an internal temperature of 76°C was reached. Flavor characteristics and texture parameters of cooked beef patties were then evaluated by a 16-member sensory panel. Fresh ground beef containing 8.5% fat and 13% fat were used as internal controls at each tasting session.

Results and Discussion

Preparation and Properties of Fantesk Products

Mixtures prepared for steam jet cooking typically contain 10–30% starch solids in water and 5–50 parts of oil or lipid per 100 parts of starch, by weight (12). Formula-

tions containing higher percentages of oil have also been processed under selected conditions. A wide variety of oils, lipids, and lipidlike materials have been used, such as soybean oil, canola oil, olive oil, semisolid hydrogenated vegetable oil, solid triglycerides, butter, beef tallow, paraffin oil, silicone oil, rosin, and organic resins. Although minor differences between some of these materials have been observed, they all behave in a qualitatively similar manner. Cornstarch was used in most of these formulations, since it is the least expensive starch of commerce; however, products have also been prepared from waxy cornstarch, high-amylose cornstarch, potato starch, wheat starch, cereal flour, and starch-protein mixtures. Although the oil component separates rapidly from uncooked formulations in the absence of stirring, jet-cooked dispersions are stable and can be stored for months without phase separation, even though no emulsifiers, stabilizers, or surface-active agents have been added.

Brookfield viscosities of jet-cooked dispersions vary with the type of oil and starch used, the oil:starch ratio, and the solids content and temperature of the cooked dispersion. Some representative viscosity values are shown in Table 20.1. Because aqueous starch is the continuous phase in all of these systems, starch type, starch solids content, and dispersion temperature are the major factors influencing the rheology and gelling properties of Fantesk dispersions. For example, at a given concentration and temperature, Fantesk dispersions prepared from starches containing high percentages of amylose (i.e., the unbranched polysaccharide component of

TABLE 20.1
Preparation and Properties of Starch-Lipid Compositions[a]

Starch variety	Lipid used	Amount (g/100 g starch)	Viscosity of dispersion after cooling[a]	
			Time standing (at 25°C)	Brookfield viscosity, cP[b]
Corn	None		Overnight	1150
Corn	Soybean oil	5	Overnight	900
Corn	Soybean oil	40	Overnight	820
Corn	Canola oil	20	3-4 h	810
Corn	Olive oil	20	3-4 h	740
Corn	Crisco	20	2-3 h	970
Corn	Butter	5	3-4 h	460
Corn	Butter	20	3-4 h	410
Corn	Butter	50	3-4 h	570
Corn	Paraffin oil	40	Overnight	900
Waxy corn	None		Overnight	360
Waxy corn	Soybean oil	40	3 h	300
			Overnight	320
Wheat	Soybean oil	40	3 h	1000
			Overnight	1100
Potato	Soybean oil	40	3 h	1660
			Overnight	3920

[a]400 g starch, 3 L water, and the required amount of lipid mixed together and jet-cooked; the jet-cooked dispersion was poured into a beaker and allowed to stand and cool without stirring.

[b]A Model LVT Brookfield Viscometer was used with No. 3 spindle at 30 rpm. Solids concentration was about 9.5–10% and varied because the dispersions were diluted with variable amounts of condensed steam.

starch) gel more rapidly and yield more rigid gels than those prepared from highly-branched amylopectin. All jet-cooked dispersions become more viscous when cooled, and at sufficiently high starch solids even dispersions prepared from waxy cornstarch (which is composed of nearly pure amylopectin) become too thick to pour. Despite their tendency to thicken and gel on standing, Fantesk dispersions become fluid and pourable once again when reheated, much like a semisolid fat or shortening. Another factor influencing rheology is the extent of shear-induced starch degradation caused by the excess steam jet cooking process. As shown in Fig. 20.2, increasing the difference between steam line pressure and pressure within the hydro-heater causes a significant reduction in the viscosity of cooked starch. Finally, if a high degree of starch degradation and a low dispersion viscosity are desired, starch-oil dispersions may simply be passed more than once through the jet cooker.

Drum drying is a practical and efficient method for isolating Fantesk from water, and drying in this manner yields a coarse, flakelike product having a water content of about 5%. These products are not oily to the touch and can be easily ground or milled into free-flowing powders. Neither drum drying nor milling causes a significant amount of oil to separate from the starch matrix. Powdered products can also be obtained by spray drying; however, the high viscosity of starch solutions makes it necessary to work at relatively low solids. It is preferable to dry these jet-cooked dispersions while they are still hot, because cooling promotes molecular association and crystallization of starch molecules through hydrogen bonding (i.e., retrograda-tion) and therefore yields Fantesk products that are not as easily redispersed in water.

Water dispersions are easily prepared from the drum-dried products by adding them to water with rapid stirring (for example, in a Waring blender) and then heating the dispersions briefly in a microwave oven. The outward appearance of these redispersed products is similar to that of the original undried material. For example, a drum-dried product prepared from 40 parts soybean oil and 100 parts starch by weight was dispersed in water at a concentration of 20 g in 200 mL. Brookfield viscosities (No. 3 spindle, 30 rpm), measured at 80, 48, and 30°C were 40, 88, and 140 cP, respectively. After 18 h at room temperature, the Brookfield viscosity increased to 1020 cP. The dispersion was smooth and creamy, and there was no separation of oil from the aqueous phase.

A useful property of Fantesk compositions is their ability to function as stabilizers for oil-water mixtures. We can utilize that property in the preparative process by adding previously prepared Fantesk materials to mixtures of starch, water, and oil when they are first formulated for jet cooking. This "add-back" procedure slows down the normally rapid separation of oil and water phases and thus eliminates the need for continuous stirring prior to cooking. The amount of "add-back" material needed is roughly 10–25% of the weight of starch used.

Although use of volatile oils and flavorings in the Fantesk process is limited by their tendency to escape as vapors during jet cooking and drum-drying, the ability of Fantesk to stabilize oil-water mixtures permits volatile oils to be added after cooking. These oils are readily absorbed by precooked Fantesk dispersions (for example, those

prepared from starch and soybean oil) and remain entrapped within the starch matrix after drying, provided that drying is carried out at a sufficiently low temperature. Volatile components are then released when the starch matrix is either scratched, broken, or dispersed in water. We have successfully entrapped both limonene and a dispersion prepared from fresh strawberries by adding these components to 10% dispersions of a 100:20 cornstarch–soybean oil composition and then allowing these mixtures to air-dry. Successful experiments with orange oil have also been carried out.

Microscopy

The size and distribution of oil droplets in Fantesk compositions are determined by several factors (13), one of which is the oil:starch ratio. The series of SEMs in Fig. 20.3 shows the effect on droplet size of increasing soybean oil content from 5 to 20 to 40 parts per 100 parts of cornstarch, by weight. As described in the "Experimental Procedures" section, films were cast from water dispersions, and the resulting air-dried films were fractured and then solvent-extracted to reveal oil droplets as voids in the fracture surface. With 5 parts oil per 100 starch, Fig. 20.3(a), oil droplet diameter was approximately 2 microns or less. Droplets were larger in film samples prepared with 20 parts of oil, as shown in Fig. 20.3(b), and at a starch:oil ratio of 100:40, as shown in Fig. 20.3(c), many of the droplets were about 10 microns in diameter.

Light microscopy was used to examine thin sections of aqueous gels that had been fixed by treatment with glutaraldehyde and osmium tetroxide. Figures 20.4(a), (b), and (c) show micrographs obtained from composites prepared from 10, 20, and 40 parts of soybean oil per 100 parts of starch, respectively. Although the size and distribution of oil droplets in these gels appears somewhat different than that observed in SEMs of air-dried films, the droplets appear to be well dispersed and show no evidence of agglomeration. Figure 20.4(d) shows a gel prepared by extracting a 20:100 oil:starch composite with hexane to remove loosely bound oil, dispersing the extracted product in water, and then stirring 10 parts of soybean oil back into the dispersion. The small size and uniform distribution of oil droplets clearly shows the ability of Fantesk compositions to accept additional oil and thus to act as stabilizers for oil-water mixtures. Figure 20.4(e) shows a gel prepared by first jet-cooking starch in the absence of oil and then mixing 20 parts soybean oil per 100 parts starch into the hot starch dispersion using a high-speed Waring blender. Although the similarity in size and distribution of oil droplets in Figs. 20.4(b) and (e) suggests that high-intensity mixing of oil with hot jet-cooked starch solutions could yield products analogous to those obtained by co-jet cooking, the co-jet cooking procedure is simpler and more suitable for continuous processing. Finally, Fig. 20.4(f) shows a gel prepared from a 40:100 oil:starch product after extracting it with hexane to remove loosely bound oil. Small, uniformly distributed droplets of unre-moved oil are clearly seen.

We have observed that the size of individual oil droplets within the aqueous starch matrix is reduced when either "add-back" material or a protein is added to the
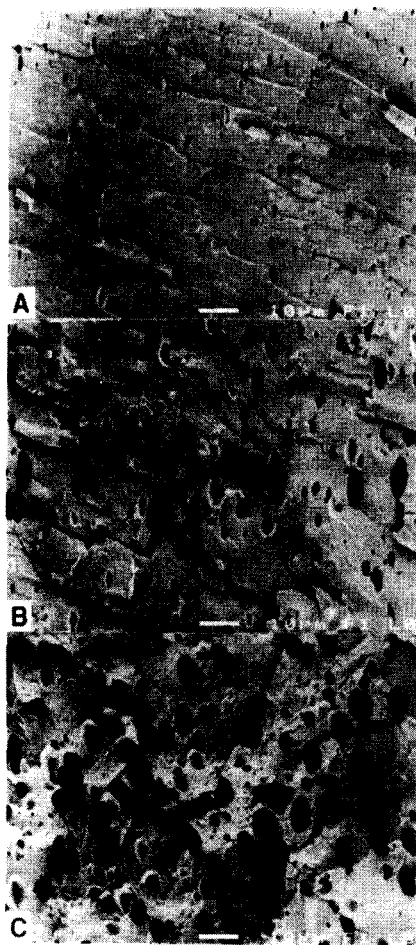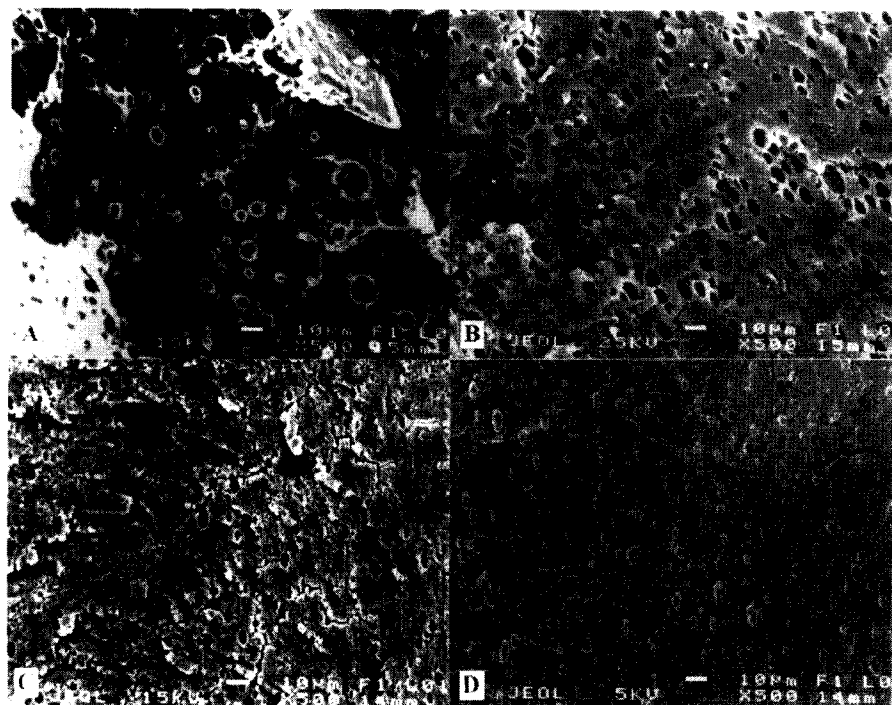
Fig. 20.3. Scanning electron micrographs of extracted fracture surface of Fantesk products prepared from cornstarch and soybean oil and then air-dried to film. (a) 5 parts oil per 100 parts starch; (b) 20 parts oil per 100 parts starch; (c) 40 parts oil per 100 parts starch.

formulation or when the volume of excess steam passing through the hydroheater during cooking is increased, as by increasing steam line pressure from 70 to 120 psig (0.48 to 0.83 MPa). Figure 20.5 compares the SEMs of 20:100 soybean oil–cornstarch products prepared under these different conditions with a control composition prepared in the absence of additives with 70 psig line pressure steam. Analysis of oil
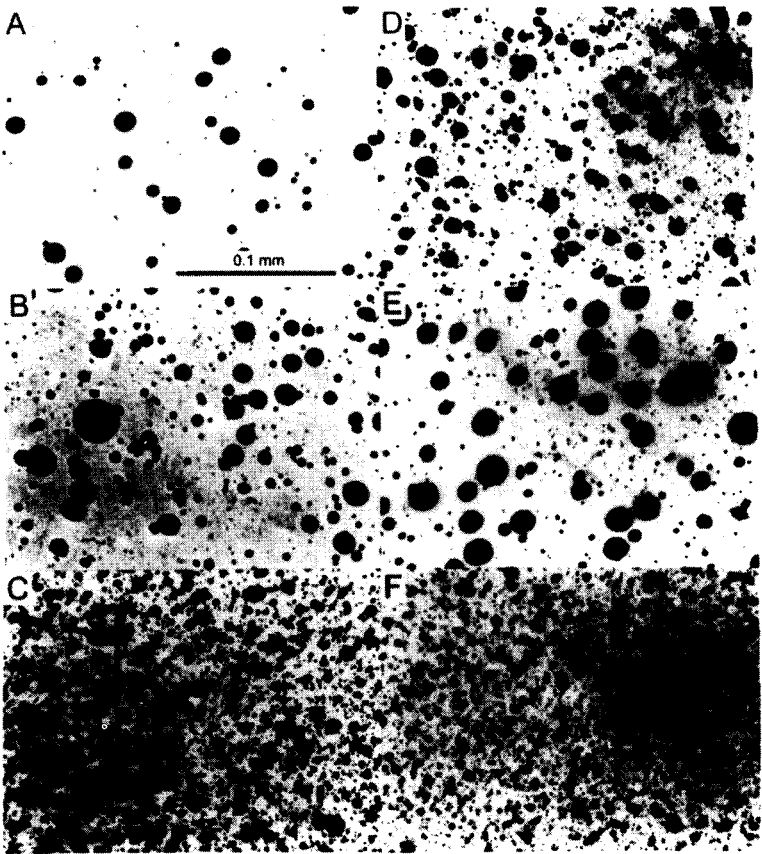
Fig. 20.4. Light micrographs of fixed, dehydrated, embedded, and sectioned samples of cornstarch–soybean oil Fantesk gels. Gels were prepared by redispersing drum-dried products in water. (a) 10 parts oil per 100 parts starch; (b) 20 parts oil per 100 parts starch; (c) 40 parts oil per 100 parts starch; (d) drum-dried Fantesk prepared with 20 parts oil per 100 parts starch and then extracted with hexane. Oil was (10 parts per hundred) added when sample was redispersed in water; (e) jet-cooked cornstarch to which oil (20 parts per hundred) was added after jet cooking; (f) drum-dried Fantesk prepared with 40 parts oil per 100 parts starch, extracted with hexane, and then redispersed in water.

droplet size in the fracture face of the control, Fig. 20.5(a), showed 328 ± 32 holes formerly occupied by oil and an average area for the individual droplets of 8.85 ± 0.89 square microns. Figure 20.5(b) shows the fracture face of an "add-back" composition; this micrograph had 421 ± 26 holes per field with an average area of 6.76 ± 0.33 square microns per droplet. Stabilization of the mixture by addition of "add-

Fig. 20.5. SEM of extracted fracture surface of Fantesk products prepared from corn-starch and soybean oil (20 parts oil per 100 parts starch) and then air-dried to film. (a) Normal jet-cooking process: 40 psig (0.28 MPa) in hydroheater, 70 psig (0.48 MPa) line pressure steam; (b) normal jet-cooking process with "add-back" material (20 parts per 100 parts starch) added to the formulation; (c) normal jet-cooking process with wheat gluten protein (20 parts per 100 parts starch) added to the formulation; (d) formulation jet-cooked using 40 psig (0.28 MPa) in hydroheater and 120 psig (0.83 MPa) line pressure steam.

back" material, therefore, not only facilitates the processing of these formulations but also yields final products having a finer dispersion of oil droplets. Figure 20.5(c) shows the SEM of a product prepared from a formulation containing 20 parts of wheat gluten protein per 100 parts starch. This fracture face contained 714 ± 21 holes per field with an average area of 1.73 ± 0.04 square microns per droplet. Proteins are known to function as emulsifiers in oil:water systems, so this reduction in oil droplet size was not unexpected. The SEM of a product prepared by jet-cooking at 40 psig but with a steam line pressure of 120 psig (rather than the 70 psig used for the control) is shown in Fig. 20.5(d). The more intense mixing within the hydroheater resulting from the greater volume of excess steam yielded a product with 552 ± 26 holes per field and an average area of 3.21 ± 0.04 square microns per droplet.

Oil droplet size can also be reduced by simply passing cooked dispersions a second time through the steam jet cooker. Figure 20.6 compares droplet size distribution in a twice-cooked composition with a product prepared by a single cook. The additional mechanical shear resulting from the second pass through the cooker decreases the average droplet diameter and sharply increases the number of droplets in the 3-micron range.

Examination of gel slices by TEM shows that oil droplets appear to be surrounded by a boundary material that stains differently than the oil and surrounding starch (Fig. 20.7). In all micrographs examined, the starch matrix is rigorously excluded from these boundaries. Although adjacent oil droplets may be in close proximity to one another, there is no apparent coalescence or merging of boundary layers, even after prolonged standing. It is interesting that when a lipopolysaccharide with bound fluorescein indicator is added to a Fantesk dispersion, it becomes concentrated within this boundary region. Although the nature of the boundary layer and the various factors leading to its formation are not known at present, research in these areas is currently in progress.

Extraction of Oil from Fantesk Compositions

Knutson et al. (14) studied the extraction of drum-dried starch-soybean oil products with hexane and showed that a significant percentage of the oil is tightly held within
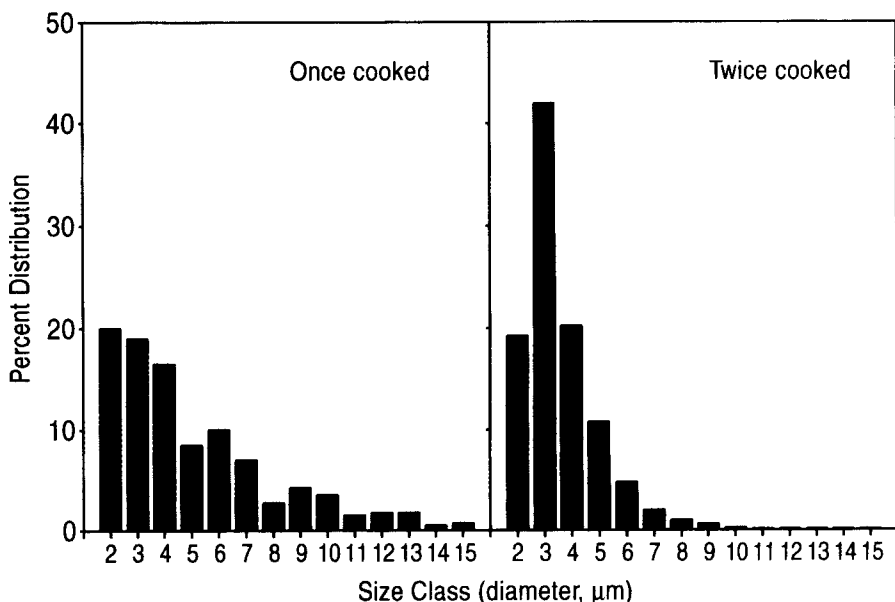
Fig. 20.6. Distribution of soybean oil droplet size in single-cooked vs. twice-cooked Fantesk products.
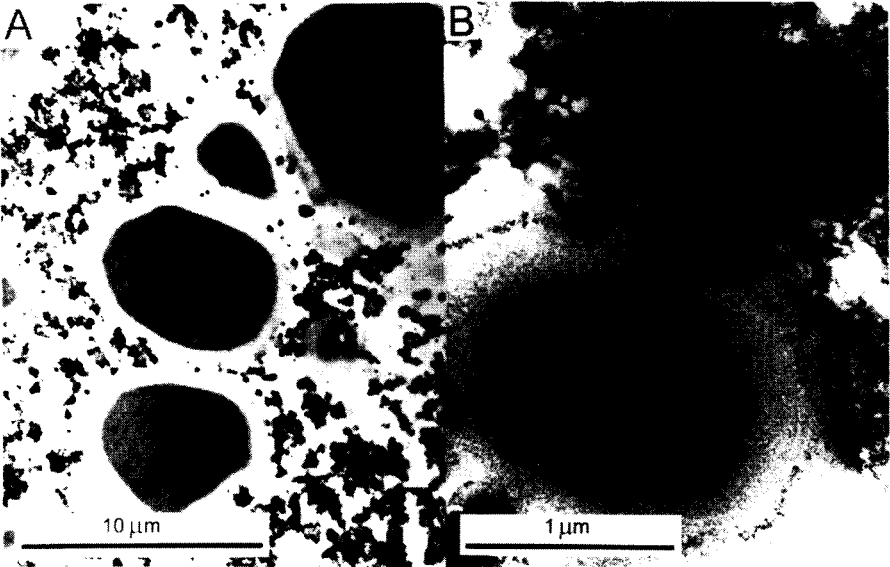
Fig. 20.7. Transmission electron micrographs of a starch–soybean oil Fantesk product showing the boundary layer that surrounds the oil droplets. Darkly stained particles in the region surrounding the oil droplets are the starch portion of the fixed and dehydrated gel.

the starch matrix and cannot be easily removed (Table 20.2). As previously mentioned, oil that could be extracted from dry products was designated as loosely bound, whereas unextractable oil was termed tightly bound. Tightly bound oil was recovered by dispersing extracted samples in water, hydrolyzing the starch moiety with α-amylase, and then extracting liberated oil from the water dispersion with hexane. Table 20.2 shows that total oil recovered from Fantesk products is significantly less than the amount of oil initially incorporated into the formulations. The reason is probably rapid separation of oil and water during the short period of time required to pump the two-phase mixture to the hydroheater. Evidence that oil separation is indeed responsible for low oil recovery was obtained by jet-cooking a formulation prepared from 100 g of cornstarch, 40 g of soybean oil, and 25 g of an "add-back" material. Using the "add-back" procedure to stabilize the oil/water/starch

TABLE 20.2
Hexane Extraction of Drum-Dried Cornstarch–Soybean Oil Products

Starch	Oil used in formulation		Oil recovered from drum-dried product		
	g oil/100 g starch	% of total wt (starch + oil)	% of drum-dried product wt	Loosely bound, % of total oil	Tightly bound, % of total oil
Normal	20	16.7	12.8	52.3	47.7
Normal	40	28.6	23.9	70.3	29.7
Waxy	40	28.6	23.4	81.6	18.4
Amylomaize VII	40	28.6	22.7	63.0	37.0

formulation resulted in recovery of over 96% of the added oil from the final product; moreover, 40.8% of the oil was tightly bound. Table 20.2 shows that amounts of tightly bound oil varied with the amylose content of the starch used for Fantesk preparation. With waxy cornstarch and 40 parts soybean oil per 100 parts starch, 18.4% of the oil was tightly bound, whereas 37% of the oil was tightly bound when cornstarch containing 70% amylose was used.

Knutson et al. (14) also studied the extraction of soybean oil from Fantesk products in water dispersion to determine whether a stable association exists between starch and oil in an aqueous medium. Fantesk products were prepared from 40 parts oil per 100 parts starch and were dispersed in water at starch concentrations ranging from 0.31 to 5.0%. Extraction results for products prepared from normal, waxy, and high-amylose starches, at a concentration of 1.25%, are shown in Fig. 20.8. Composites prepared from normal and waxy cornstarches behaved similarly, and about 50% of the total oil could be removed with eight hexane extractions. In contrast, about 90% of the oil was removed in five extractions from control samples prepared by simple mixing of soybean oil with either jet-cooked or granular normal cornstarch. The Fantesk
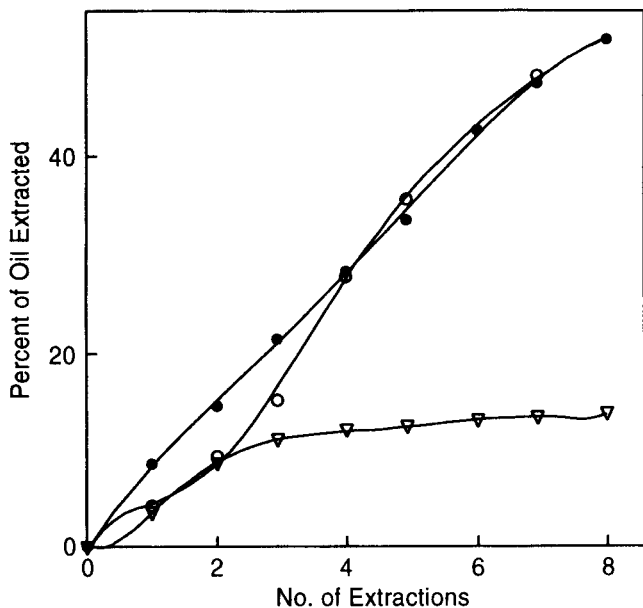
Fig. 20.8. Hexane extraction of oil from Fantesk products in aqueous dispersion. Products were prepared from 40 parts soybean oil per 100 parts starch, drum-dried, and then dispersed in water at a starch concentration of 1.25%. Open circles: Fantesk prepared with normal cornstarch; filled circles: Fantesk prepared with waxy cornstarch; triangles: Fantesk prepared with high-amylose cornstarch.

product prepared from high-amylose cornstarch behaved differently and released only 14% of its total oil after eight extractions. Examination of the aqueous suspension revealed that a significant amount of the solid material had swelled but was not completely redispersed in hot water. This fraction could be separated by centrifugation and was found to be resistant to enzyme hydrolysis. When this fraction was redried and finely ground, additional oil could be extracted from the dried material.

The rate of oil extraction increased with decreasing concentrations of Fantesk in water; and at the lowest concentration examined (0.31%), essentially all of the oil could be removed from a composite prepared from 20 parts oil per 100 parts normal cornstarch (14). Similar extraction of a material prepared from 40 parts of oil removed 80% of the total oil present. There thus appears to be no sharp demarcation between loosely bound and tightly bound oil when Fantesk is extracted in water dispersion. It appears likely that most of the oil can be extracted from a given Fantesk product, provided that the number of extractions is sufficiently large and the aqueous dispersion is sufficiently dilute.

End-Use Applications

Food Products. The smoothness and lubricity of Fantesk compositions in aqueous dispersion suggest their use as thickeners, stabilizers, and fat substitutes in food products; materials for these applications have been prepared by co-jet cooking starches with food-grade lipids such as vegetable oils, butter, and animal fats (e.g., beef tallow). Fantesk products may be added to food formulations as dry powders, reconstituted aqueous dispersions, or undried dispersions obtained directly from the steam jet cooker. It is expected that Fantesk products will be quickly approved for use in foods, since chemical reactions are not used in the preparative process; and the procedure only requires cooking a mixture of ingredients at high temperature and pressure.

Fantesk products function as fat replacers in food products because the lipid component is finely dispersed within the starch-water matrix as micron-sized droplets and can, therefore, provide many of the flavor characteristics of higher-fat products, even though lipid is present in relatively small amounts. For example, we have prepared frozen desserts having excellent flavor and texture that contain as little as 0.5% fat. Low-fat salad dressings have also been prepared by using Fantesk as the lipid component. Since fat substitutes are used in low-fat cheeses, yogurts, and cream fillings, these areas of application are also being examined.

The baking industry also provides a large potential market for fat replacers, and Fantesk products can be easily added as dry powders to instant cake formulations to replace a portion of the shortening that is normally used. Fantesk can also be used to reduce the high fat content of cookies, pastries, and biscuits.

Another use for Fantesk products is as a coating for microwave popcorn. Tests in our Laboratory have shown that water dispersions of Fantesk, prepared with butter or vegetable oil as the lipid component, form continuous and uniform coatings when dried onto popcorn kernels. The dried coatings adhere tenaciously because the lipid

component improves compatability between the starch-based coating and the waxy seed surface. Popcorn coated in this manner pops readily when heated in a microwave oven and has good flavor characteristics.

Fantesk can function as an effective flavor carrier in foods, because the lipid component makes these products receptive to the addition of a wide variety of essential oils and flavorings. Even though many flavoring components are volatile, they remain entrapped within the starch matrix after low-temperature drying and are released only when the dried composite is scratched, broken, or dispersed in water. We have used the flavor-carrying properties of Fantesk to impart flavors such as butter, cheese, onion, and garlic to microwave popcorn and to low-fat salad dressings.

The use of Fantesk products to improve the flavor and texture of low-fat meats could provide a large market for these materials, and we have cooperated with a local meat processor to study the influence of Fantesk on the flavor and texture of low-fat ground beef patties (15). Products for this study were prepared from either normal food grade cornstarch, waxy cornstarch, or high-amylose cornstarch; and the lipid component was either beef tallow or soybean oil. Soy protein or wheat gluten was also used in these formulations; since preliminary experiments showed that protein serves as a binder and helps keep beef patties from breaking apart during cooking. The weight ratio of starch:lipid:protein was held constant at 80:32:20. Although steam pressure within the hydroheater was held constant at 40 psig (0.28 MPa), steam line pressures of both 70 and 120 psig (0.48 and 0.83 MPa) were investigated, because of the known effect of excess steam on the molecular weight and rheological properties of cooked starch. The 12 products listed in Table 20.3 were prepared according to a statistical design to investigate the combined effects of these variables on product properties.

Flavor characteristics and texture parameters of cooked beef patties were evaluated by a trained sensory panel. The beef used for blending with Fantesk contained 8.5% fat, and fresh ground beef samples containing 8.5% fat and 13% fat, respectively, were used as internal controls at each tasting session. Addition of Fantesk

TABLE 20.3
**Fantesk Products Prepared For Addition to Ground Beef**

| Code	Starch	Lipid	Protein	Steam pressure (psig)
FG/T/S	Normal	Tallow	Soy	120
FG/T/W	Normal	Tallow	Wheat	65
FG/S/S	Normal	Soybean oil	Soy	65
FG/S/W	Normal	Soybean oil	Wheat	120
A/T/S	Normal+high-amylose	Tallow	Soy	65
A/T/W	Normal+high-amylose	Tallow	Wheat	120
A/S/S	Normal+high-amylose	Soybean oil	Soy	120
A/S/W	Normal+high-amylose	Soybean oil	Wheat	65
W/T/S	Waxy	Tallow	Soy	65
W/T/W	Waxy	Tallow	Wheat	120
W/S/S	Waxy	Soy oil	Soy	120
W/S/W	Waxy	Soy oil	Wheat	65

influenced the beef and fatty flavors of cooked beef patties and also the texture para-
meters of juiciness and chewiness. Five of the six beef samples containing Fantesk
prepared from tallow were rated as not significantly different in beef flavor intensity
than the control patties containing 8.5% fat (Fig. 20.9). All but one of the samples
containing Fantesk prepared from soybean oil had less beef flavor than the 8.5% fat
control. Figure 20.10 shows that three of the Fantesk products produced fatty flavor
intensities that were not significantly different from the 13% fat control. Patties
containing two of the Fantesk products prepared from high-amylose starch and
soybean oil (A/S/S and A/S/W) were significantly more juicy than the 8.5% fat
control (Fig. 20.11); and five of the six soybean oil–containing Fantesk samples gave
cooked patties that were significantly more tender than the 13% fat control (Fig.
20.12). Although this preliminary study is not sufficient to determine the optimum
Fantesk formulation for use in low-fat ground beef, it is a starting point for more
detailed studies that could lead to the commercial use of Fantesk in meat products.

   Licensing for food applications of Fantesk is currently being investigated by the
U.S. Department of Agriculture (USDA). A patent application has also been filed by
the USDA and Opta covering the use of Fantesk in meat products.

Adhesives, Coatings, and Other Industrial Applications. Fantesk compositions
containing rosin derivatives, resins, and tackifiers have been prepared, and these
materials are being evaluated as adhesives for particleboard. Urea-formaldehyde
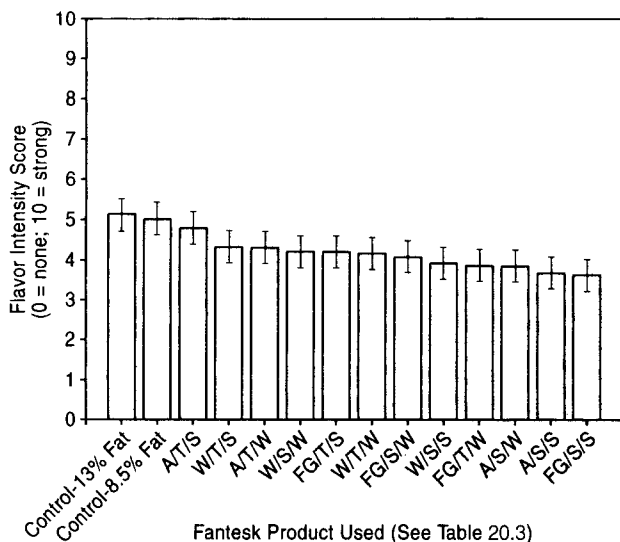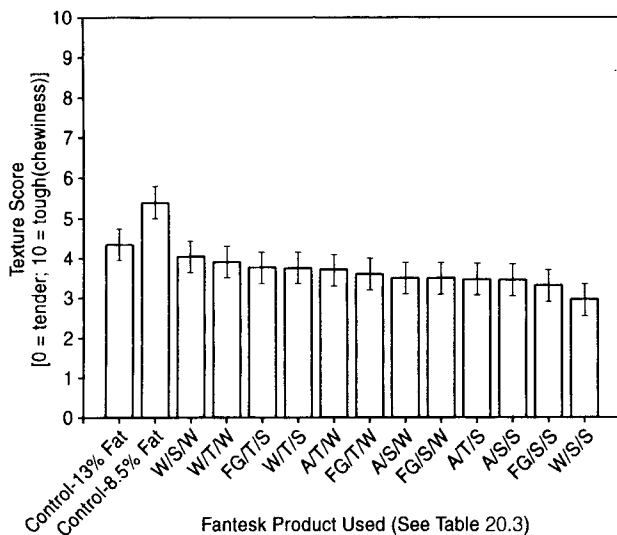

Fig. 20.9. Effect of various Fantesk products on the intensity
of beef flavor in ground beef patties.
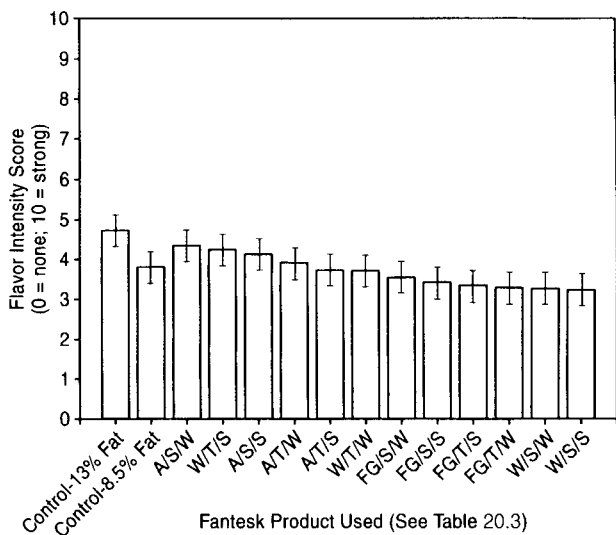
Fig. 20.10. Effect of various Fantesk products on the intensity of fatty flavor in ground beef patties.
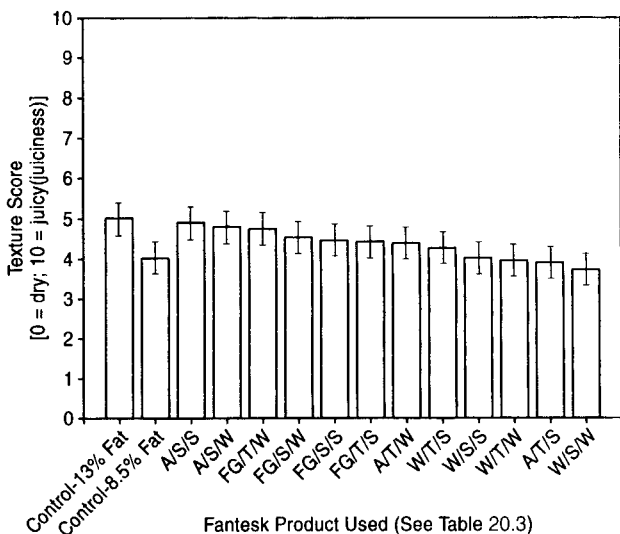
Fig. 20.11. Effect of various Fantesk products on the juiciness of ground beef patties.

Fig. 20.12. Effect of various Fantesk products on the chewiness (i.e., toughness) of ground beef patties.

resins are currently used for particleboard production; use of low-cost Fantesk products in these adhesive formulations would not only provide an economic advantage but would reduce the amount of toxic formaldehyde used. Starch is reactive toward formaldehyde, so it can also act as a scavenger to reduce the amount of formaldehyde vapor released into the atmosphere by the finished wood products.

Fantesk compositions containing paraffins and waxes are being tested as water-resistant coatings for boxboard. Also, because of the high lubricity of many of these Fantesk products in water dispersion, the Fantesk technology is being investigated as an inexpensive method for preparing water-based lubricants and oil-drilling fluids.

A license for the use of Fantesk products as adhesives, industrial lubricants, and coatings for paper and boxboard was granted to a major corporation by the U.S. Department of Agriculture. We are working with another company under a Cooperative Research and Development Agreement to develop Fantesk products for oil field applications.

Cosmetic and Medicinal Applications. Since Fantesk products prepared from paraffin and silicone oils have a smooth, creamy consistency when dispersed in water, and the oil component does not separate on standing, these materials have applications in cosmetics, skin care formulations, and drug delivery systems. Medicinal agents, drugs, and compounds such as fatty acids and vitamins A and E can also be incorporated into these products. We have been in contact with several companies to develop products for these applications.

Seed Coating. When seeds are covered with an aqueous Fantesk dispersion and then allowed to dry, a uniform coating is formed that adheres tightly to the waxy seed surface. These coatings can function as carriers for a wide variety of pesticides, herbicides, plant growth regulators, and microorganisms (for example, *Rhizobium*). Since the starch portion of the Fantesk coating imbibes water readily, it can also function as a water absorbent, attracting and holding water at the seed surface and thus enhancing the germination process. Fantesk coatings can also be tailored to protect the seed from moisture by incorporating large amounts of hydrophobic materials such as paraffins and waxes into the formulation. Retarding the rate of water absorption by the seed, and thus increasing the length of time needed for germination, is often desirable when crops are planted in the early spring, when ground moisture is high but temperatures are too low for rapid germination and seedling growth. Finally, it is often desirable to apply a heavy clay coating to small-diameter seeds to increase their size and weight and thus facilitate planting. The use of Fantesk formulations as binders in these clay formulations is being investigated.

The U.S. Department of Agriculture has granted an exclusive license to Seedbiotics, Caldwell, Idaho, for the use of Fantesk products for seed coating applications.

Acknowledgments

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